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Radiation Exposures from a Cesium-Contaminated Field

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RADIATION EXPOSURES FROM A CESIUM-CONTAMINATED FIELD

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ABSTRACT

A surface radiological investigation was conducted at the 0800 Environmental Research Area between June 1987 and March 1988 by the Measurement Applications and Development group, Oak Ridge National Laboratory. The purposes of this scoping survey were (1) to measure current gamma exposure rate levels at the contaminated enclosures and on the river and riverbanks, which are used for fishing and other types of recreation; (2) to provide a radiological impact analysis for this site, including dose estimates for current exposure pathways according to worst-case scenarios; (3) to calculate exposure rates after shielding the contaminated enclosures with soil or concrete of various thicknesses; and (4) to recommend corrective actions to minimize exposures to the general public and workers on the Oak Ridge Reservation (ORR), if warranted.

Outside the fenced area, radiation levels were measured at 23 points on the Clinch River and 9 points along the riverbank. Gamma exposure rates on the river and on Jones Island rarely exceeded background. Along the shoreline, the closest point to the ^{137}Cs-contaminated field approached three times background levels, a value well below the guideline. Thus, this site poses no hazard to the public.

Inside the fenced area, the average gamma exposure rate at 1 m above the ground surface was approximately 3 to 4 mR/h. Maximum exposures exceeded 27 mR/h at one of the contaminated enclosures. At the maximum exposure rate, the permitted limit on annual dose equivalent for radiation workers of 5 rem would be exceeded within seven weeks.

Strict monitoring and control of access to the fenced area are recommended. If the site is accessed only on a limited basis, it represents no serious potential radiological health hazard to workers. Should frequent access be required, corrective actions are suggested.

INTRODUCTION

Because of civil defense interest in postattack survival, a weapons fallout field study was commissioned at Oak Ridge National Laboratory (ORNL) during 1966. The fallout study used ^{137}Cs (an important long-lived component of weapons fallout) as the source of radiation. This radionuclide has a 30-year half-life and emits both beta (0.52- and 1.18-MeV) and gamma (0.66-MeV) radiation.[1]

The 2-ha (5-acre) fenced area used for the ^{137}Cs fallout study is part of the 0800 Environmental Research Area, a ~20-ha (50-acre) fescue-dominated field located 100 m (330 ft) north of the Clinch River at Clinch River Kilometer 32.8 (Mile 20.5).[2] The study area is also located ~2.1 km south of the intersection of Bethel Valley Road and State Highway 95[1] at ORNL grid coordinates (measured in feet) North 17,480 and East 20,370.[2]

Within the fenced area, eight 10- by 10-m (33- by 33-ft) treatment plots were enclosed by metal sheeting extending 45 cm (18 in.) below the surface and 61 cm (24 in.) above ground. In August 1968, enclosures 2, 4, 6, and 7 (see Fig. 1) were contaminated with ^{137}Cs, and the remaining four enclosures were used as controls.[2]

The contaminant consisted of ^{137}Cs fused at high temperatures to silica sand particles (100 μCi/g). The particles ranged from 88 to 177 μm in diameter and were spread at a load of 72 g/m^2 over the plots.[3] Each enclosure received approximately 2.2 Ci of ^{137}Cs, which resulted in a total of 8.8 Ci to the site. The particle-size distribution was selected to simulate particle diameters characteristic of weapons fallout. Foliage and soil were contaminated directly by sedimentation with the fraction intercepted by foliage subject to weathering losses to the litter and soil.[1]

During the period of experimental observation, vegetation clippings and soil cores were removed from the enclosures, analyzed, and disposed of according to ORNL procedures. The remaining radioactivity has been subject to weathering and radiological decay. Nearly 20 years (~0.67 half-life) have passed since the enclosures were contaminated. With radiological decay accounted for, a total of ~5.5 Ci of activity would remain today, assuming no particle losses due to weathering, runoff, or wind transport. The remaining activity of ^{137}Cs in each contaminated enclosure would be ~1.4 Ci as of 1988. The site is currently inactive (see Figs. 2 and 3).[1]

In 1983, two radioisotopes were used in an area isolated from the original ^{137}Cs-contaminated pens but within the 2-ha fenced enclosure. In May, July, and September, ^{131}I was sprayed on a pasture area of 4000 m^2. The total activity was 60 mCi. In September, 10 mCi of ^{95m}Tc was also applied. The purpose of the study was to assess the transfer of these radioisotopes from forage grass to milk in goats.

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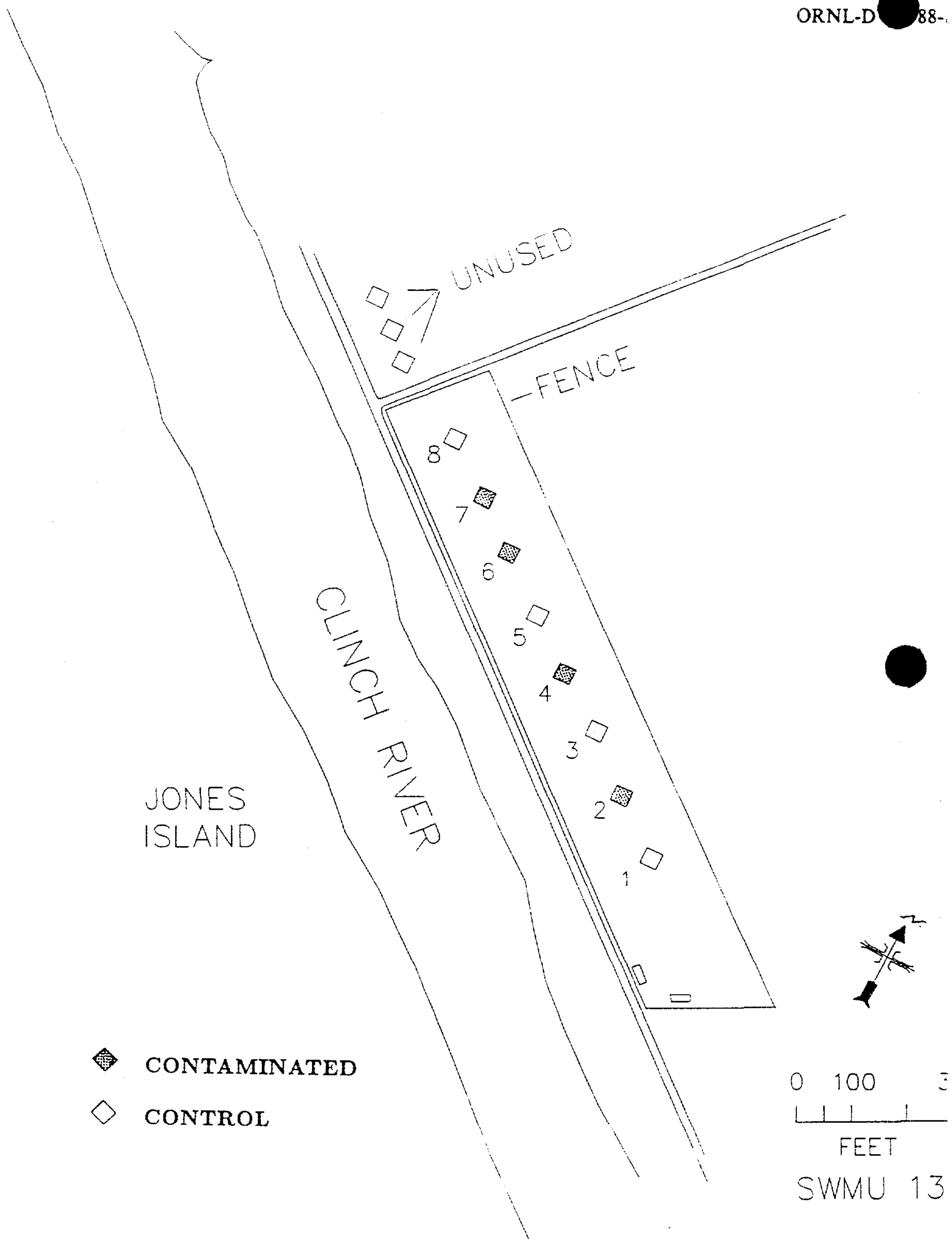

Fig. 1. Location of the 2-ha fenced area with eight enclosures used in fallout studies at the 0800 research area. The four shaded enclosures were contaminated with ^{137}Cs; [illegible] remaining four were controls.

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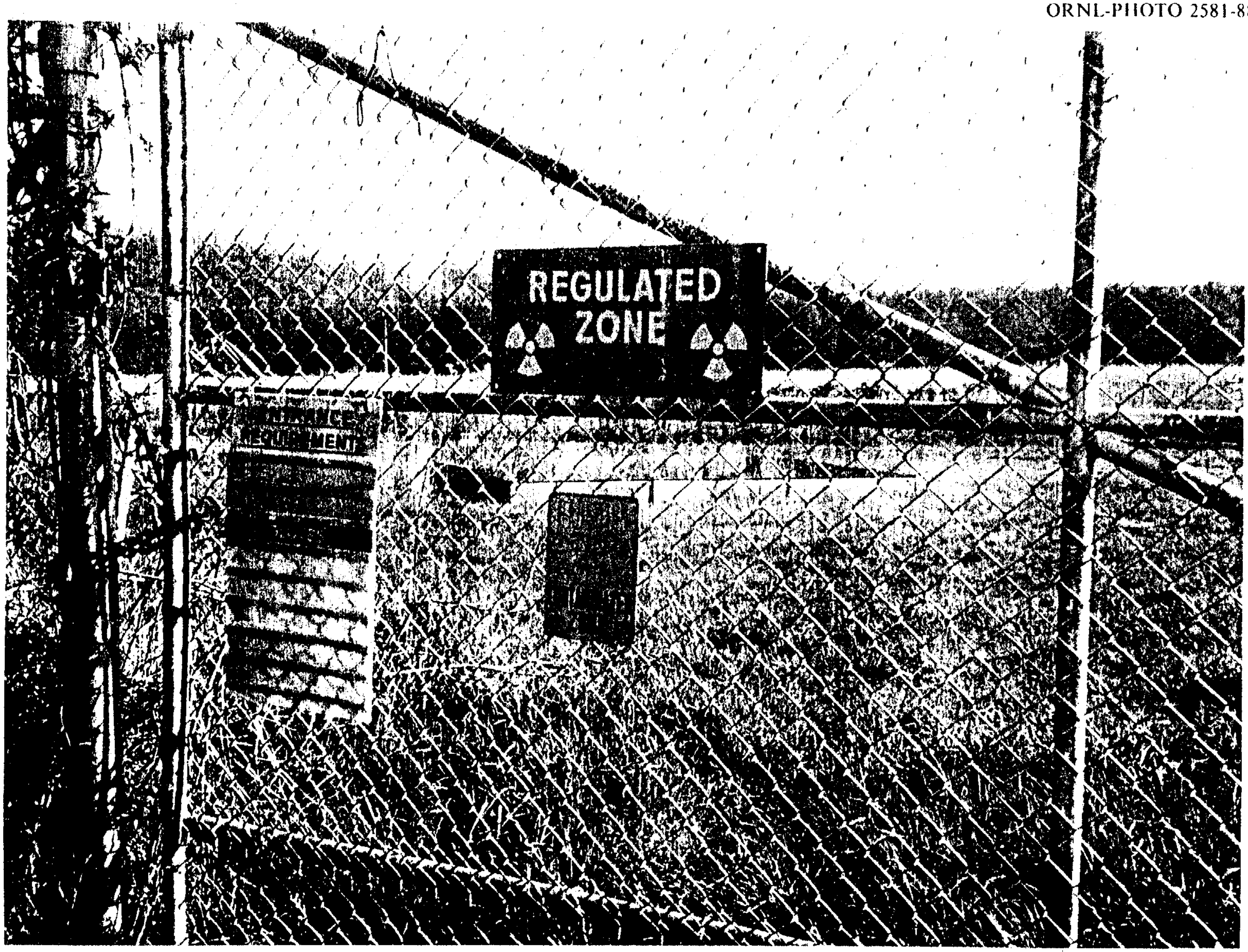

Fig. 2. View looking east at an entrance gate to the cesium-contaminated field.

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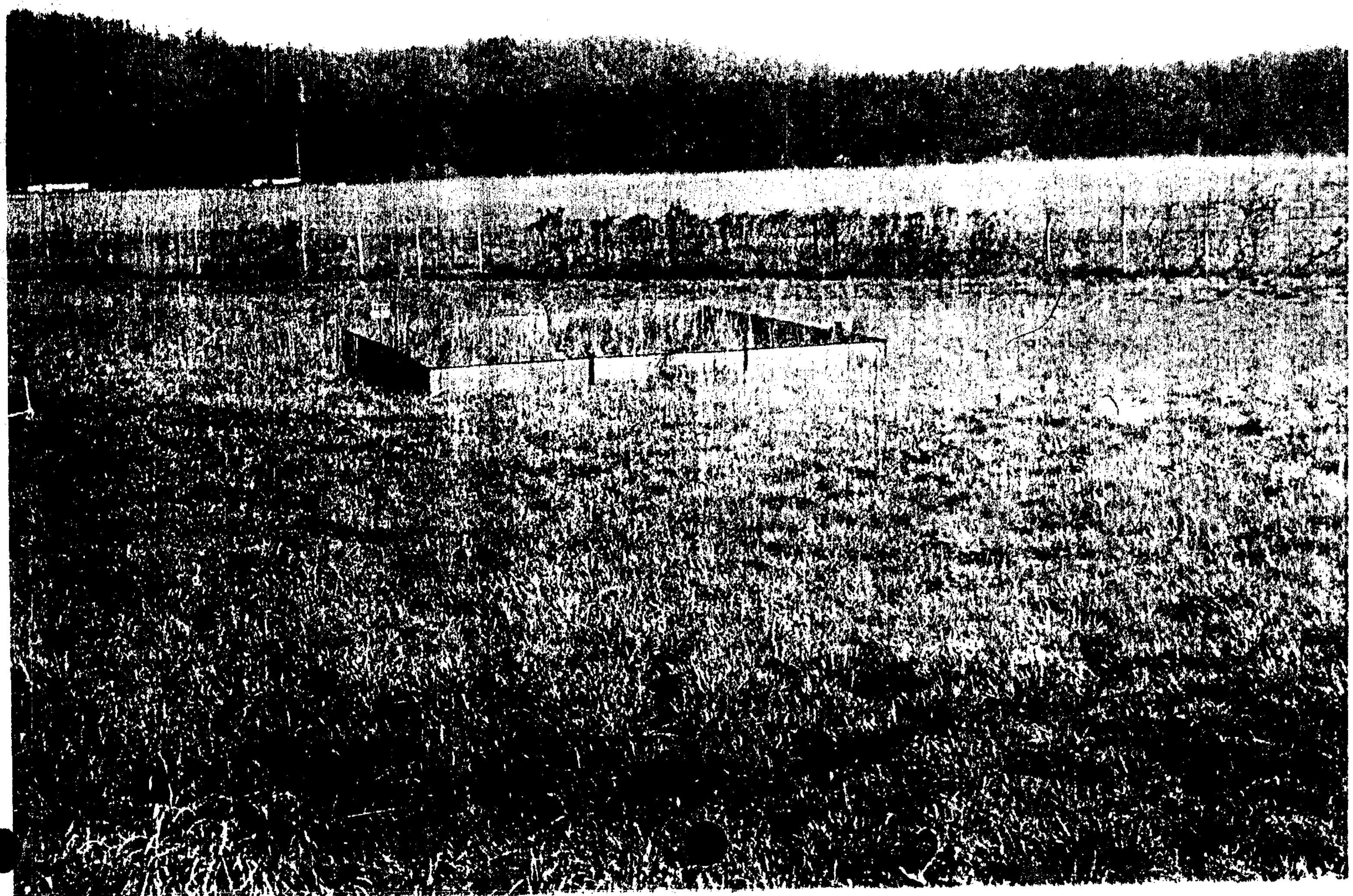

Radioactivity of both isotopes is currently not detectable because of losses due to radiological decay. As of 1988, approximately 27 and 204 half-lives have passed for ^{95m}Tc and ^{131}I, respectively.[1]

In 1986, an aerial radiometric survey of the White Oak Creek/White Oak Lake watershed indicated the presence of ^{137}Cs in the 0800 area. At an altitude of 46 m (150 ft) over the fenced area, ^{137}Cs count rates ranged from 46,000 to 100,000 counts per second.[4]

In 1987, a single soil sample was taken from the bed of a small (<30 cm wide) creek, which drains the 0800 area to the northeast during periods of high runoff. The sample contained ^{137}Cs contamination (11 nCi/kg) and ^{90}Sr (0.57 nCi/kg) about twice that of background for Conasauga Shale (<0.27 nCi/kg).[5]

Additional soil samples taken in 1987 from two locations between the original ^{137}Cs plots and the creekbed indicated that ^{137}Cs had migrated. The measured concentrations of 16 and 62 nCi/kg were 15 to 60 times background levels of 1.1 nCi/kg.[6]

The purposes of the current study were (1) to measure current gamma exposure rate levels at the contaminated enclosures and on the river and riverbanks, which are used for fishing and other types of recreation; (2) to provide a radiological impact analysis for this site, including dose estimates for current exposure pathways according to worst-case scenarios; (3) to calculate exposure rates after shielding the contaminated enclosures with soil or concrete of various thicknesses; and (4) to recommend corrective actions to minimize exposures to the general public and workers on the Oak Ridge Reservation (ORR), if warranted.

SURVEY METHODS

A comprehensive description of the radiological survey methods and instrumentation used by the Measurement Applications and Development group has been presented in *Procedures Manual for the ORNL Radiological Survey Activities (RASA) Program.*[7] Because of high activity close to the contaminated enclosures, slight deviations from routine survey procedures were made in order to reduce working time in the field and, therefore, minimize the exposure of survey crew members to radiation.

In June 1987, gamma exposure rate measurements were made with a pressurized ionization chamber (PIC) at 1 m above the ground surface at the southwest corner of each enclosure. Since scintillation counters and Geiger-Muller (GM) survey meters reached saturation in this area, only the PIC could be used near the contaminated enclosures. Away from the contaminated enclosures measurements were also made with scintillation counters. The PIC had a diameter of 31.75 cm so that the center of the chamber was located approximately 15 cm from the ground during surface measurements.

In March 1988, additional measurements were made at enclosure 4, which had the highest exposure rates; these included location 4.1 at 1 m above the ground surface on the north side, location 4.2 at 1 m in the center, and location 4.3 at 15 cm above the ground surface in the center.

In September 1987, gamma exposure rates were measured at 1 m at 23 points th Clinch River and at 9 points along the river on the ORR and on Jones Island (Fig. 4). T determine exposure rates on the river, the PIC was placed on a boat and readings wer taken at 1 m above the bottom of the boat (Fig. 5).

In order to convert the scintillation counter measurements, which were in thousands c counts per minute (kcpm), to microroentgens per hour (μR/h), measurements were mad with both the scintillation counter (kcpm) and the PIC (μR/h). The kcpm measurement were plotted versus the μR/h measurements at the same points, and Minitab© was used t calculate a linear regression line that best fit the data.[8] For this site, the best-fit value were: slope = 2.4 and intercept = −141. Thus, the following relationship was used fo conversion of the scintillation counter measurements over 60 kcpm.

$$\mu R/h = 2.4 \times kcpm - 141 .$$

SHIELDING CALCULATIONS

A computer code, MICROSHIELD 3.07©, written for the IBM PC, was used t determine the thickness of the shield necessary to reduce exposure rates at this site.[9] Thi program is a microcomputer adaptation of the mainframe code ISOSHLD II.[10] The cod uses numerical integration of the point kernel expression, including photon buildup, in th calculation of shielding for different geometries of the source and shield. In addition, th user may define a special shielding material of specified atomic com tion MICROSHIELD 3.07© contains a library of more than 400 radioactive isotopes, includin the energy and probability per decay for emission of gamma rays. Solution algorithms ar provided for 16 different geometries.

In this study it was assumed that the geometry of the source was a rectangular volun of soil containing ^{137}Cs distributed uniformly within the soil. The penetration of ^{137}C into the soil over the years was measured in a soil sample taken from enclosure 4. Th field measurement indicated that ^{137}Cs had migrated to a depth of ~16 cm. Therefor the dimensions of the rectangular volume for the source were approximately 10 × 9 × 0.16 m (33 × 30 × 0.5 ft). The composition of soil and the percentage of commo elements in soil were taken from *CRC Handbook of Chemistry and Physics*, 64t edition.[11] The density of the soil (2.0 g/cm^3) was taken from *The Health Physics an Radiological Health Handbook*.[12]

Based on these assumptions and the assumption that radiation levels can be reduce with a slab shield, calculations were performed to determine the thickness of shieldir required to reduce exposure levels in the area. For these calculations, soil and concre slabs were selected as possible shielding materials.

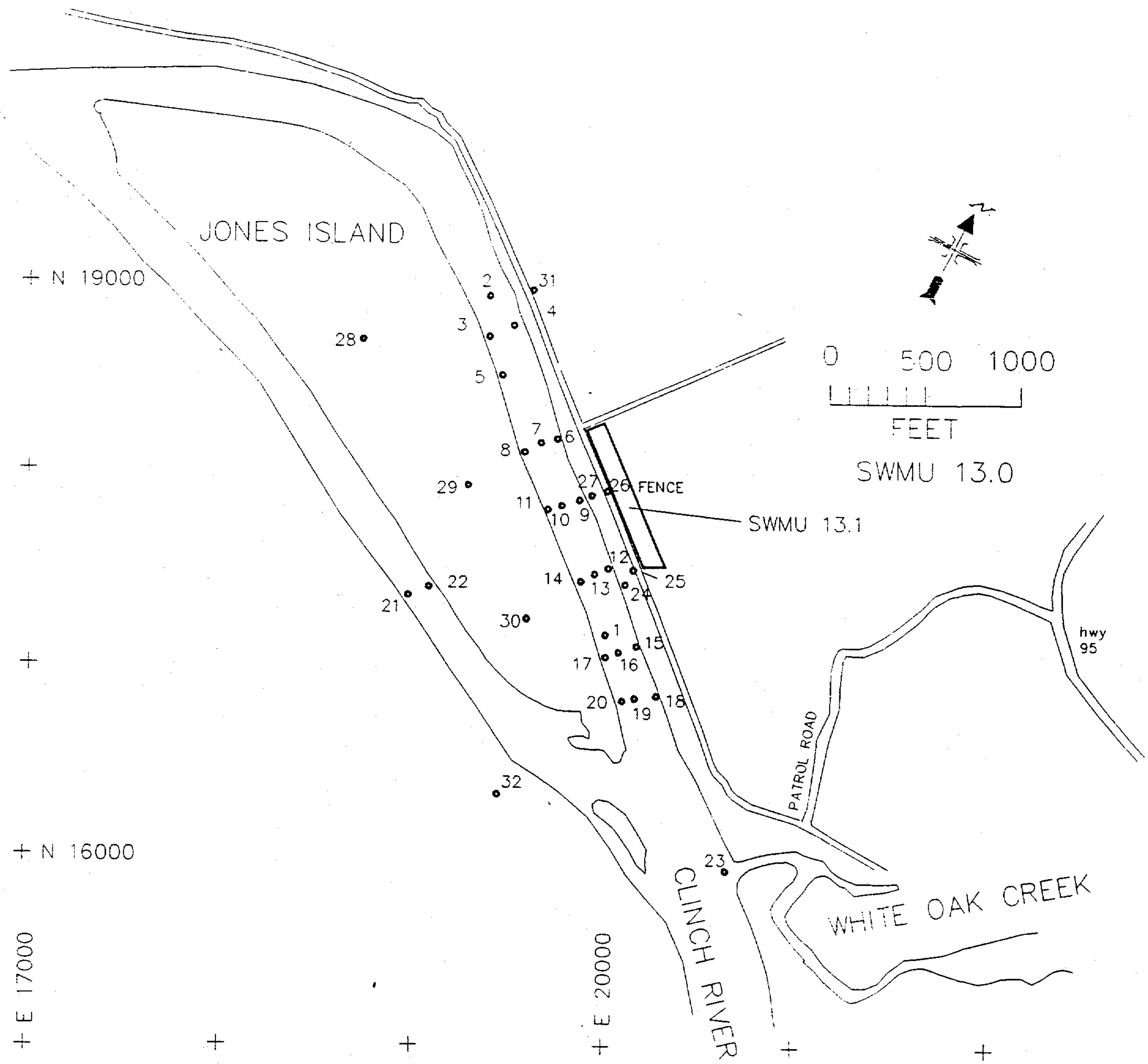

Fig. 4. Locations of gamma measurements taken outside the fenced area on the river (points 1–23) and on the banks along the river and Jones Island (points 24–32).

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SURVEY RESULTS

BACKGROUND LEVELS

Background exposure rates at 1 m were determined to be 6 μR/h over the surface water of the Clinch River and 10 μR/h on the land at uncontaminated points distant from the contaminated field. All measurements presented in this report are gross readings; background radiation levels have not been subtracted. Minitab© was used for the statistical analyses performed in this report.[8]

GAMMA MEASUREMENTS

The results of gamma exposure rate measurements inside the four contaminated enclosures are presented in Table 1 and Fig. 6. Table 1 also contains calculated exposure rates after shielding with 15 cm of soil, 50 cm of soil, 4 cm of concrete, or 25 cm of concrete. Figure 6 shows gamma exposure rates measured in the contaminated enclosures with calculated exposure rates after shielding with 50 cm of soil in parentheses. Gamma measurements indicate that the three enclosures located outside the fenced area are not contaminated.

Table 1. Results of gamma exposure rate measurements at the southwest corners of the cesium-contaminated enclosures and calculated exposure rates at the same points after indicated shielding

	Measured gamma exposure rate at 1 m	Calculated exposure rates at 1 m after shielding[c]			
Enclosure[a,b]	(μR/h)	15 cm soil (μR/h)	50 cm soil (μR/h)	4 cm concrete (μR/h)	25 cm concrete (μR/h)
2	1,300	140	2	610	14
4	5,600	590	8	2,600	62
4.1[d]	27,000	2,900	38	12,000	300
4.2[e]	28,000	2,900	39	13,000	300
4.3[f]	35,000	3,700	49	16,000	390
6	1,800	200	3	850	20
7	4,000	420	6	1,800	44

[a]Enclosures are shown on Fig. 1.

[b]Enclosures 1, 3, 5, and 8 were used as uncontaminated controls.

[c]Values represent calculated exposure rates using Microshield 3.07©. Actual exposure rates cannot be reduced below background levels of ~10 μR/h at 1 m.

[d]Measurement taken at the north side of enclosure 4.

[e]Measurement taken at the center of enclosure 4.

[f]Measurement taken 15 cm above the surface at the center of enclosure 4.

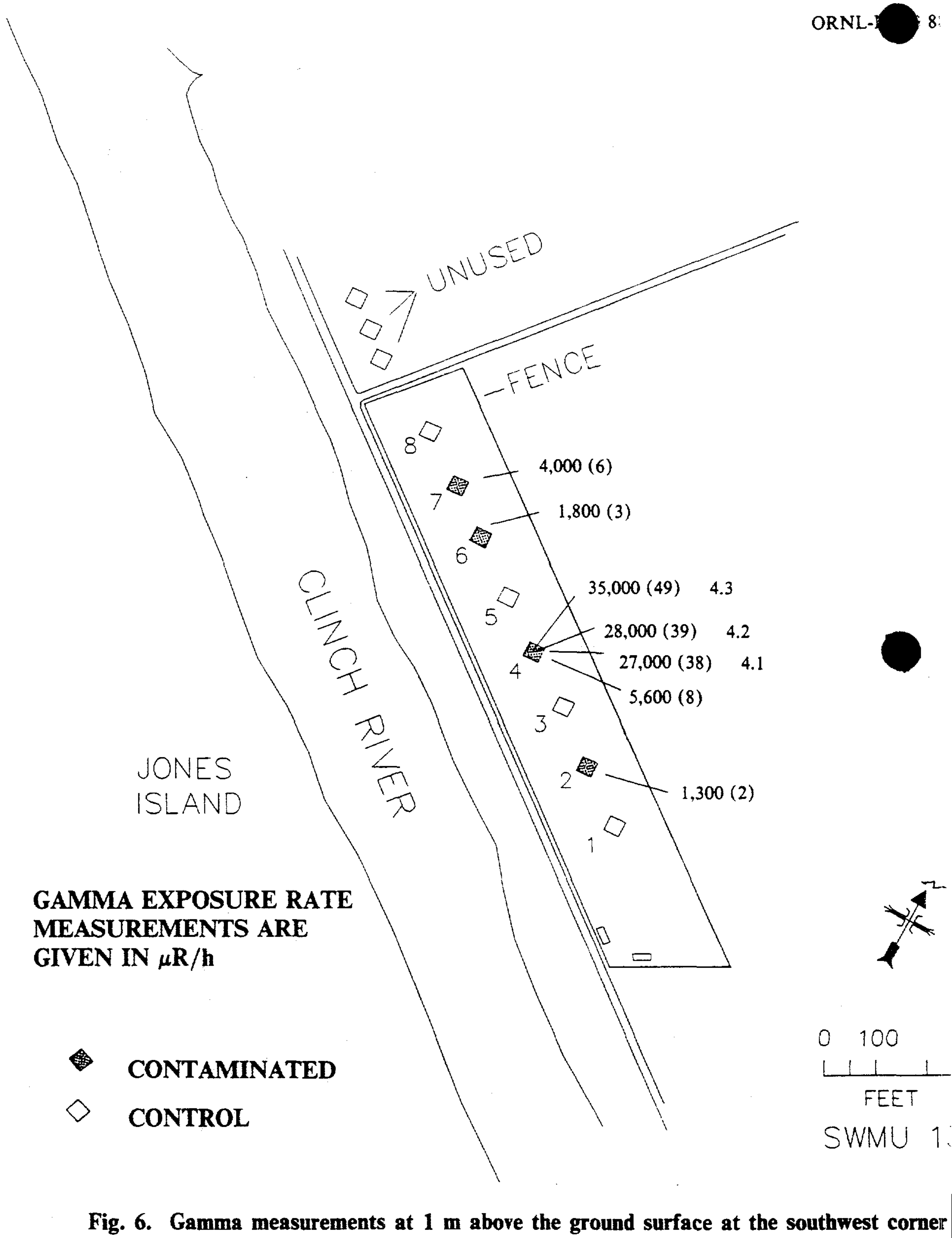

Fig. 6. Gamma measurements at 1 m above the ground surface at the southwest corner of contaminated enclosures. Calculated exposure rates after shielding with 50 cm of soil are given in parentheses. Additional measurement points at enclosure 4 included: location 4.1 north side at 1 m, location 4.2 center at 1 m, and location 4.3 center at 15 cm above the surface.

Inside the fenced area and around the contaminated enclosures, gamma exposure rates at 1 m ranged from 0.052 mR/h to 27 mR/h and averaged 3.4 mR/h, with a standard deviation of $\pm$8.9 mR/h and a median of 0.11 mR/h. In the center of enclosure 4, gamma exposure rates were 28 mR/h at 1 m and 35 mR/h at 15 cm above the surface. Gamma exposure rates decreased significantly as distance from the enclosures increased. For example, along the fence, which is approximately 25 m (82 ft) from the enclosures, gamma exposure rates at 1 m ranged from 0.04 mR/h to 0.15 mR/h and averaged 0.08 $\pm$ 0.04 mR/h, with a median of 0.059 mR/h.

The results of gamma exposure measurements at 1 m at points along the Clinch River are presented in Table 2 along with calculated exposure rates at the same points after shielding the contaminated enclosures with 5 cm of soil, 15 cm of soil, or 4 cm of concrete. Similarly, measured gamma exposure rates at 1 m over the surface of the Clinch River are shown in Table 3 along with calculated exposures. Figure 7 locates the measured values on the map and includes (in parentheses) the calculated exposure rates after shielding the contaminated enclosures with 5 cm of soil.

Table 2. Results of gamma exposure rate measurements at points along the Clinch River and calculated exposure rates at the same points after indicated shielding of the cesium-contaminated enclosures

Point of measurement[a]	Estimated coordinates		Measured gamma exposure rate at 1 m (μR/h)	Calculated exposure rates at 1 m after shielding the contaminated enclosures[b]		
	North	East		5 cm soil (μR/h)	15 cm soil (μR/h)	4 cm concrete (μR/h)
24	17,400	20,100	12	6	1	6
25	17,475	20,150	14	7	1	7
26	17,900	20,000	52	25	5	24
27	17,875	19,925	29	14	3	14
28	18,700	18,750	6	3	1	3
29	17,925	19,275	9	5	1	5
30	17,225	19,625	8	4	1	4
31	19,000	19,625	10	5	1	5
32	16,325	19,600	10	5	1	5

[a]Locations of points are shown on Fig. 5.

[b]Values represent calculated exposure rates using Microshield 3.07©. Actual exposure rates cannot be reduced below background levels of ~10 μR/h at 1 m.

Table 3. Results of gamma exposure rate measurements over the Clinch River and calculated exposure rates at the same points after indicated shielding of the cesium-contaminated enclosures

Point of measurement[a]	Estimated coordinates		Measured gamma exposure rate at 1 m (μR/h)	Calculated exposure rates at 1 m after shielding the contaminated enclosures[b]		
	North	East		5 cm soil (μR/h)	15 cm soil (μR/h)	4 cm concrete (μR/h)
1	17,150	20,000	6	3	1	3
2	18,900	19,375	7	3	1	3
3	18,750	19,300	7	3	1	3
4	18,800	19,600	6	3	1	3
5	18,450	19,425	7	3	1	3
6	18,175	19,775	15	7	2	7
7	18,150	19,700	12	6	1	6
8	18,075	19,575	9	4	1	4
9	17,850	19,900	19	9	2	9
10	17,825	19,775	13	6	1	6
11	17,800	19,700	10	5	1	4
12	17,500	20,025	19	9	2	9
13	17,450	19,950	14	7	2	[illegible]
14	17,425	19,850	11	5	1	5
15	17,125	20,150	8	4	1	4
16	17,075	20,075	8	4	1	4
17	17,025	19,975	8	4	1	4
18	16,875	20,275	6	3	1	3
19	16,850	20,150	6	3	1	3
20	16,800	20,050	5	2	0.5	2
21	17,350	19,000	5	2	0.5	2
22	17,375	19,100	6	3	1	3
23	15,925	20,675	5	2	0.5	2

[a]Locations of points are shown on Fig. 5.

[b]Values represent calculated exposured rates using Microshield 3.07©. Actual exposure rate cannot be reduced below background levels of ~6 μR/h at 1 m over surface water of the Clinch River.

DISCUSSION

The exposure rate measurements taken at this environmental research area were used to estimate potential radiation doses that could be received over different time intervals in two worst-case hypothetical scenarios. These scenarios provide conservative estimates of potential doses to fishermen or workers in the area.

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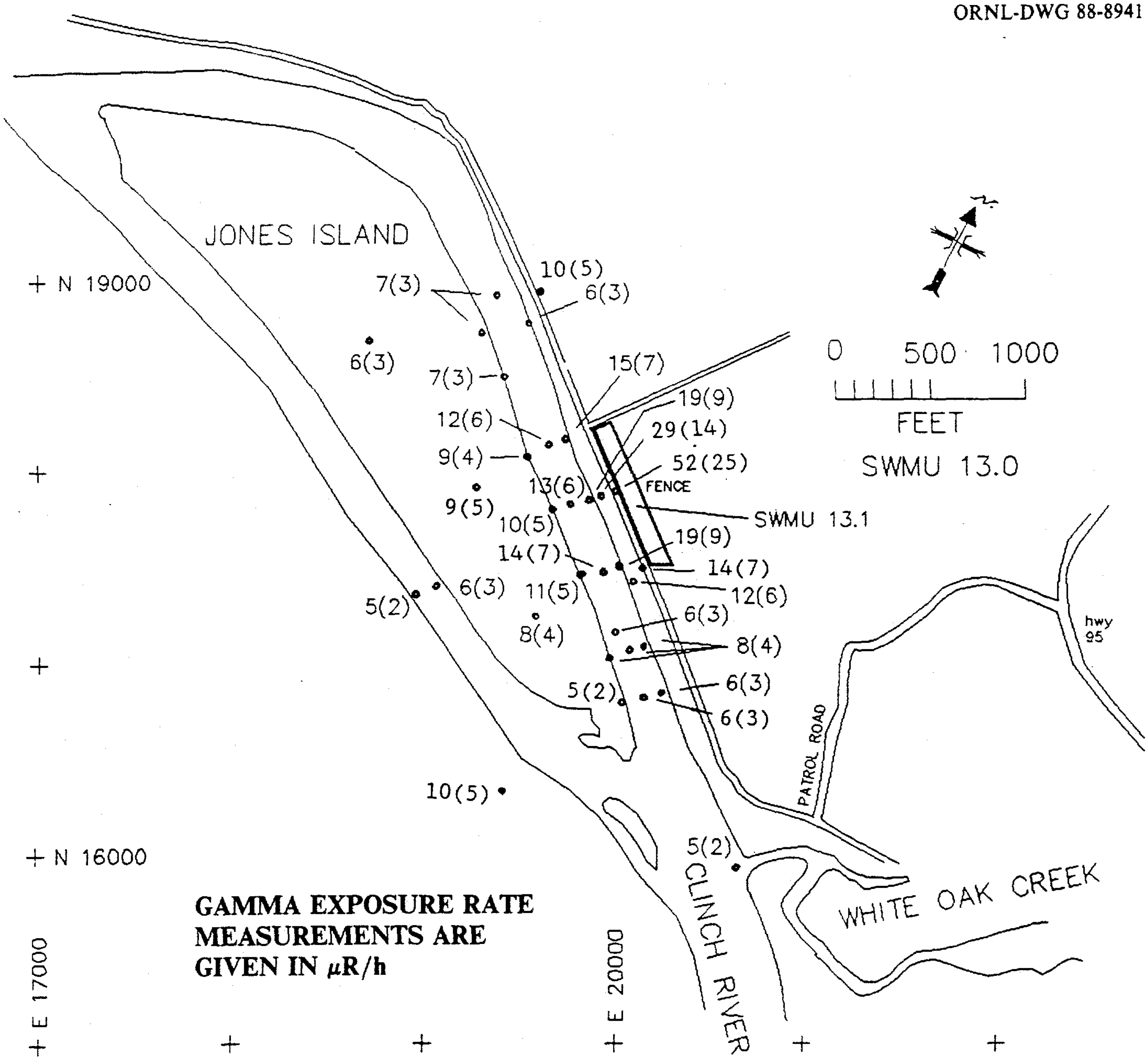

Fig. 7. Gamma measurements at 1 m above the ground surface at points outside the fenced area. Calculated exposure rates after shielding with 5 cm of soil are given in parentheses.

The radiological impact analysis of this site takes into consideration the fact that the site is located on the ORR and is visited infrequently. It also assumes that consumption of radioactive deer meat is not a valid exposure pathway because deer killed on the ORR are monitored for radioactivity before release to hunters.

THE FISHERMAN SCENARIO

- Because this site borders the Clinch River, it is a common site for fishermen, who may spend 52 hours per year (2 hours per week, 26 weeks per year) fishing on the river or along the shoreline. The fisherman may receive external exposure emanating from the cesium-contaminated field as well as an internal dose from ingestion of contaminated fish.

- Gamma exposure rates along the shoreline and on the river (Table 3) reached a maximum of 19 μR/h. Thus, a fisherman spending 52 hours per year along the shore could receive an external gamma dose equivalent of about 0.7 mrem per year.* Additionally, the fisherman could receive an effective dose equivalent as large as 0.3 mrem per year from consuming contaminated fish.[13]

THE WORKER SCENARIO

- The site is used by members of the Environmental Sciences Division for research purposes, and ORNL service personnel spend time on the field for maintenance activities such as mowing the grass. An individual may spend 25 hours per year on the site where he/she is exposed to radiation externally from contaminated ground and internally from inhalation of radioactive particles that have been suspended in the air from surface contamination.

- Assuming an external exposure rate of 3.4 mR/h (average measured value) inside the fenced area, an individual spending 25 hours per year inside the fence could receive an external gamma dose equivalent of about 60 mrem per year.* Using the inhalation conversion factor for ^{137}Cs,[14] the inhalation dose equivalent for the same individual would be 3.6 x 10^{-5} mrem per year.

Material originally deposited on the ground surface may undergo resuspension in air through wind action. The factors affecting resuspension are wind speed, particle size, weathering, and the migration of surface deposits into deeper soil. The models presented offer different values, ranging between 10^{-9} and 10^{-4}, for resuspension rates.[14] Because there is not much disturbance at this site, the lower end of the spectrum, 10^{-9}, was used as the resuspension factor.

RECOMMENDATIONS

Estimated external gamma dose equivalents under the proposed assumptions are approximately 1 mrem per year for a fisherman and 60 mrem per year for an individual who may work in the fenced area according to the scenarios presented in this study.

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*Air exposure of 1 R is approximately equal to a dose equivalent to whole body (or effective dose equivalent) for an exposed individual of about 0.7 rem (personal communication, D. C. Kocher, Health and Safety Research Division, ORNL).

Because these are conservative estimates, this site represents no serious potential radiological health hazard to the public or to the worker.

However, it has long been recognized by radiation control professionals that it is prudent to avoid unnecessary exposure and to hold doses as low as is reasonably achievable (ALARA).[15] This is determined in most cases by the state of the technology and the economics of the improvements in relation to the anticipated benefits from these improvements. The objective of efforts to ensure ALARA exposures in occupational settings is to further reduce avoidable exposures and thereby minimize the low risks that are presumed to result from small doses.

This study predicts insignificant potential occupational hazard for an individual spending 25 hours per year inside the fence. However, a worker spending 20 hours per week and 50 weeks per year near the contaminated enclosures could exceed the permitted limit on annual dose equivalent for radiation workers of 5 rem.[16] Therefore, with this remote possibility in mind, the following recommendations are presented for consideration.

- Access to the fenced area should be strictly monitored. If the site is occupied more than 25 hours per year by any one individual, then access to the fenced area should be restricted and controlled. In the event that the site *must* be accessed on a frequent basis, the following corrective action options should be considered: (1) covering the four contaminated enclosures, (2) erecting a rope or fence barrier around the contaminated enclosures, or (3) removing the contaminated soil to an approved disposal site.

- If covering the four contaminated enclosures is deemed appropriate, then clean, uncontaminated soil is the preferred covering material. Concrete would be more difficult to apply and more difficult to remove in the future. Soil thicknesses required to reduce yearly occupational exposure rates below the permitted limit on annual dose equivalent of 5 rem[16] are shown in Table 4. With 5 cm of soil on enclosures 2 and 6, and 15 cm of soil on enclosures 4 and 7, annual doses would be reduced to less than one-fifth the permitted limit. For these estimates, no consideration was given to problems such as erosion, weathering, intrusion by rodents, and other engineering predicaments.

- Because covering a contaminated area can add to the volume of contaminated soil that must eventually be disposed of, alternatives to covering should also be considered. Gamma exposure rates 2 m (6.6 ft) from enclosure 4 are 1.8 mR/h. Annual dose equivalents at this point, based on 40 hours per week and 50 weeks per year, thus would be about one-half the permitted limit. Therefore, an alternative to covering is to place a rope or fence barrier around enclosures 2, 4, 6, and 7 at a distance of 2 m (6.6 ft) from the perimeter of each enclosure. Signs that prohibit access to the circumscribed areas should also be posted.

- Another alternative to covering is excavation and removal of the contaminated soil to a designated disposal site. This corrective action must be carried out in full compliance with guidelines stated in the *Health, Safety, and Environmental Protection Procedures for Excavating Operations* manual [ORNL/M-116/R1 (March 1988)].

Table 4. Results of gamma exposure rate measurements at the southwest corners of the cesium-contaminated enclosures and calculated exposure rates at the same points after recommended shielding

Enclosure[a,b]	Measured gamma exposure rate at 1 m (μR/h)	Calculated exposure rates at 1 m after recommended shielding[c]		Estimated annual dose equivale after shielding[d,e] (mrem)[f]
		5 cm soil (μR/h)	15 cm soil (μR/h)	
2	1,300	420	—	590
4	5,600	—	590	830
6	1,800	590	—	830
7	4,000	—	420	590

[a]Enclosures are shown on Fig. 1.

[b]Enclosures 1, 3, 5, and 8 were used as uncontaminated controls.

[c]Values represent calculated exposure rates using Microshield 3.07©.

[d]Based on 40 hours per week and 50 weeks per year.

[e]Permitted limit on annual dose equivalent for radiation workers is 5000 mrem (Environmen Protection, Safety, and Health Protection Program for DOE Operations, Order 5480.1, 1981).

[f]Air exposure of 1 R is approximately equal to a dose equivalent to whole body (or effecti dose equivalent) for an exposed individual of about 0.7 rem (personal communication, D. Kocher, Health and Safety Research Division, ORNL).

CONCLUSION AND SUMMARY

An environmental research area was contaminated with ^{137}Cs in 1968 in order perform fallout studies. The Measurement Applications and Development group wa asked to perform a radiological survey in the area and to determine the potential f radiological impact of this site on the public and on workers. The findings presented i this report were based on survey measurements taken in the 0800 area between June 198 and March 1988.

Outside the fenced area, measurements were made on the Clinch River and on Jon Island. Exposure rates in this area rarely exceeded background. Along the shoreline, th closest point to the ^{137}Cs-contaminated field approached three times background levels, value well below the guideline. Thus, the site poses no hazard to the public.

Inside the fenced area, the average exposure rate was approximately 3 to 4 mR/ Maximum exposures exceeded 27 mR/h at some points. At the maximum exposure ra the permitted limit on annual dose equivalent for radiation workers of 5 rem would b exceeded within seven weeks.

Strict monitoring of access to the fenced area is recommended. If the site is pie only on a limited basis, it represents no serious potential radiological health hazard t workers. If the site *must* be used on a frequent basis, the following corrective action options should be considered: (1) covering the four contaminated enclosures; (2) erecting a rope or fence barrier around the contaminated enclosures; or (3) removing the contaminated soil to a designated disposal site.

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